Millimeter Wave Scattering from Ice Crystals and Their Aggregates

Research Highlight

Observational data sets are needed to drive and evaluate results from cloud-resolving model (CRM) simulations in order to improve parameterizations of the physical processes. Radar is one of the few observing systems that provides continuous observations of large spatial extent of cloud systems, with the additional advantage that the sampling resolution is similar to CRM grid-volumes, but comparisons require a transformation from model variable space (e.g., particle size distribution) to radar measurement space (e.g., radar reflectivity). Interpretation of radar measurements of clouds and precipitation requires an accurate understanding of the electromagnetic scattering characteristics of hydrometeors.

Until recently, highly complex-shaped hydrometeors, such as ice crystal aggregates, have been modeled using an equivalent representation of their dielectric properties. This “bulk” (or “soft sphere”) model approach consists of modeling an aggregate as a sphere or spheroid composed of a mixture of ice and air. One of the main limitations of this approach in representing a heterogeneous particle (e.g., a snowflake) as a homogeneous one is resonance effects. These resonance effects result in oscillations in the backscattering cross sections for particles comparable in dimension to half a wavelength and larger. A homogeneous particle with a smooth shape such as a sphere or spheroid enhances these resonance effects. However, the complex irregular structure of ice crystal aggregates is not well represented by homogeneous spheres or spheroids.

This study deals with observations from arctic mixed-phase clouds, where the dominant contribution to radar reflectivity is due to ice hydrometeors. In the particular case considered here, the ice particles are dendritic crystals and their aggregates, with sizes exceeding half the wavelength at 35 GHz and reaching half the wavelength at 9 GHz. Given these circumstances, a direct comparison of CRM-derived and measured radar reflectivities requires due consideration of the electromagnetic scattering calculations of the ice hydrometeors. A single layer, mixed-phase cloud observed on April 8th, 2008, during the Indirect and Semi-Direct Aerosol Campaign (ISDAC) is the subject of this study. The CRM study of this case is described in detail in Avramov et al. (2011); this paper presents the electromagnetic scattering calculations.

The ice crystal and ice crystal aggregate modeling technique presented in this work employs the Generalized Multiparticle Mie (GMM) method. GMM is an analytical solution of Maxwell’s equations for a cluster of arbitrarily located, non-overlapping spheres, each with arbitrary size and dielectric constant.

An ice crystal aggregate is represented by a collection of pristine ice crystals, each of which is modeled as a cluster of tiny ice spheres. The constituent pristine crystals have random orientation, position, and size. The basic assumption of this approach is that the scattering properties of an aggregate can be approximated by this cluster of spheres representing the original aggregate. This is a reasonable approximation as long as the spheres in the cluster are distributed in a manner that closely resembles the mass distribution of the original aggregate and are small enough to reproduce the microphysical properties of the constituent ice crystals.

The objective of this study was to evaluate results of a CRM using cloud radar measurements. Several radar backscattering models were used to transform the CRM-produced ice hydrometeor populations to radar reflectivities at Ka- and X-band radar frequencies. It was found that a refined representation of the ice hydrometeors,

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both pristine crystals and their aggregates, is required in order to obtain comparable CRM-domain reflectivity histograms to actual radar measurements.

When using a bulk model representation for ice hydrometeors together with the CRM PSDs, reflectivity histograms were shifted below the radar measurements by more than 15 dB. Bulk model approaches were less accurate, especially at Ka-band, because of resonances in the backscattering cross sections for aggregate sizes exceeding half the wavelength, resulting in the underestimation of radar reflectivity.

It is anticipated that at frequencies above Ka-band (e.g., W-band), bulk models of aggregates and pristine crystals will experience resonance effects at all sizes of aggregates greater than about 1.6 mm. With the proliferation of cloud-research radars operating at these millimeter-wave band frequencies, it is essential to consider refined models such as the one described here.

Comparison of CRM products with in situ measurements alone is not sufficiently definitive in discriminating between the model parameterizations. It is demonstrated here that the addition of radar-model comparison analysis leads to more discrimination, if refined scattering models of ice particles are incorporated in the evaluations.

Reference(s)

Botta G, K Aydin, J Verlinde, A Avramov, A Ackerman, A Fridlind, M Wolde, and G McFarquhar. 2011. "Millimeter wave scattering from ice crystals and their aggregates: Comparing cloud model simulations with X- and Ka-band radar measurements." Journal of Geophysical Research – Atmospheres, 116, D00T04, doi:10.1029/2011JD015909.

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